Informing the **Transmission Discussion**

A Look at Renewables Integration and Resilience Issues for Power Transmission in Selected Regions of the United States

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scottmadden MANAGEMENT CONSULTANTS

WIRES

Regional Discussion

SOUTHWEST POWER POOL

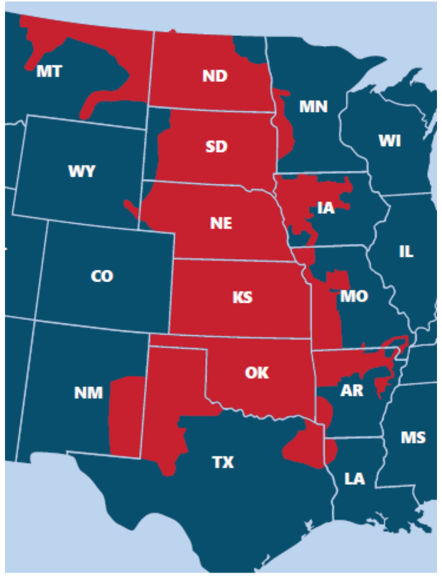
Contents

Overview

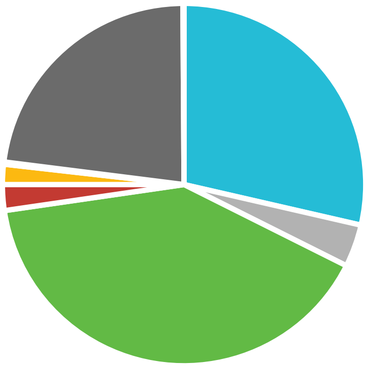
- The Southwest Power Pool (SPP) footprint covers 575,000 square miles and encompasses all or parts of 14 states: Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming.
- Wind penetration in SPP has increased significantly, from 38% of peak in 2015 to nearly 70% of peak in 2018.
- In its latest reliability report, SPP projects thermal generation retirements of nearly 2 GWs over the next 10 years: 896 MWs of coal along with 1,145 MWs of natural gas, although it does not expect reliability impacts from retirements.

Key Regional Statistics	
States Covered	AR, IA, KS, LA, MN, MO, MT, NE, NM, ND, OK, SD, TX, WY
Square Mi. Covered	~546,000
No. of Utilities	16 investor-owned utilities; 14 munis; 20 generation & transmission co-ops; 8 state agencies; 1 federal agency
No. of Customers/Pop. Served	17.5MM population
Installed Capacity	164,037 MWs
Transmission Line Miles	66,892 miles
Peak Hour Demand (2018)†	49,926 MWs summer (43,584 MWs winter)
Energy Production (2018)	275,887 GWhs
Forecast Growth (Annual)	0.07% peak load growth† 0.92% energy growth

SPP's Regional Footprint



2018 Capacity Mix by Fuel



Source: SPP

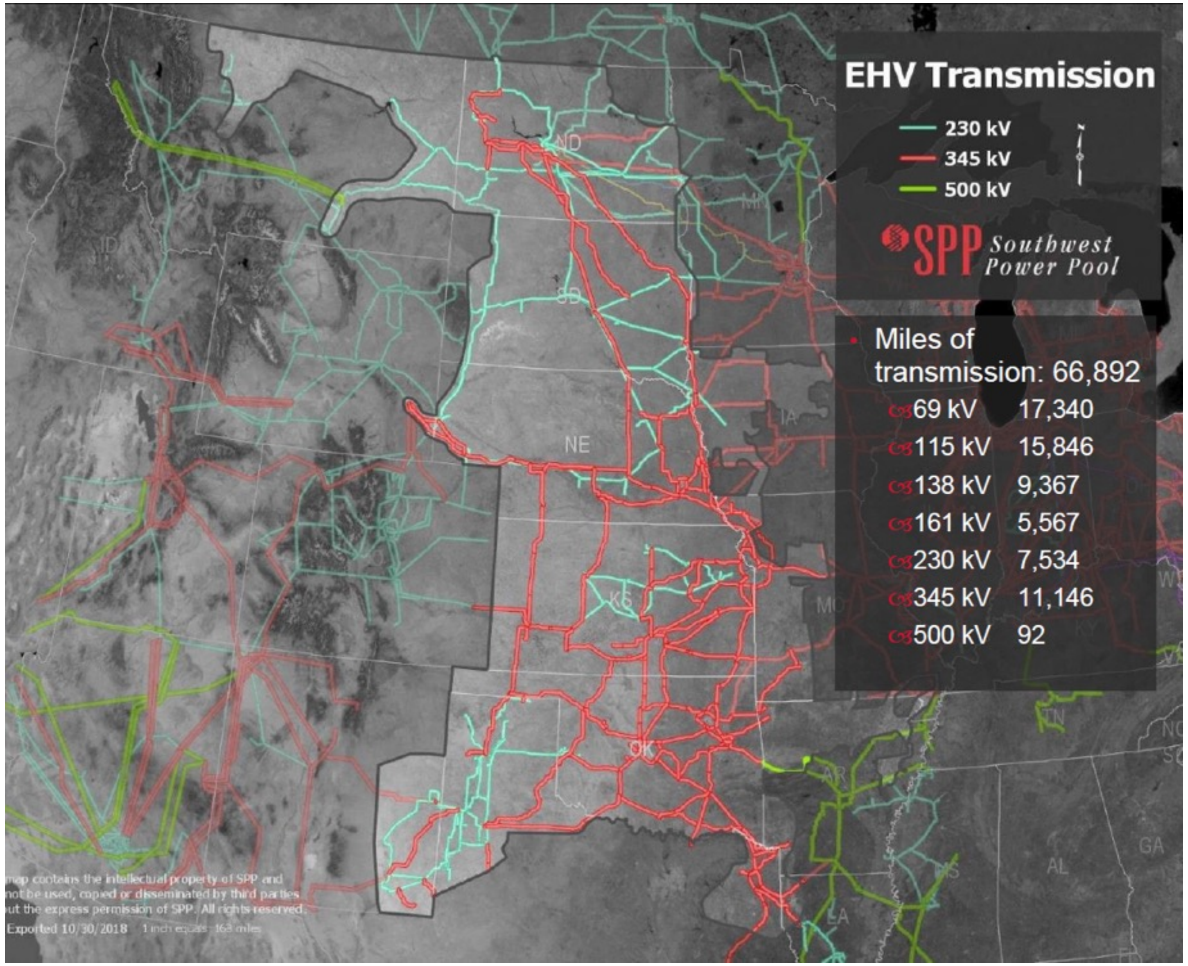
2018 Energy Mix* by Fuel

Source: SPP

Sources: NERC 2018 LTRA; Intro to SPP; SPP 101; SPP SOM 2018
Notes: † Non-coincident.

Transmission Topography and Investment

SPP's High-Voltage Transmission System



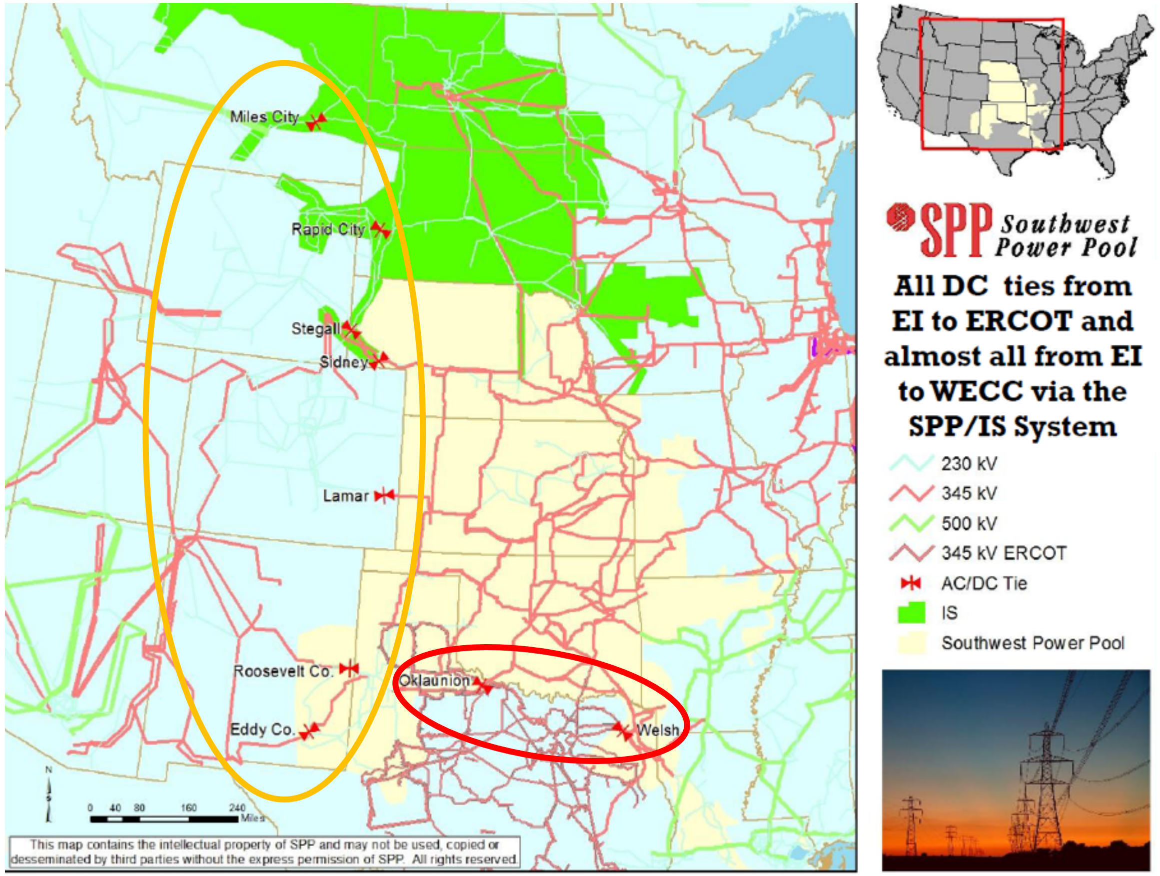
Source: SPP

- SPP has an extensive transmission network, reaching from Canada to Texas, with nearly 19,000 miles of transmission 230 kV or above (28% of its system).
- Its region is bounded by the Midcontinent ISO (MISO) to the east, SERC to the southeast, the Electric Reliability Council of Texas (ERCOT) to the south, and the Western Interconnection to the west.
- It has expanded over the past 15 years. Initially covering Kansas, Oklahoma, the Texas Panhandle, areas in Missouri, Arkansas, New Mexico, and Louisiana upon its creation in 2004. It now extends northward to the Canadian border, eastward into Iowa, and westward into Montana.
  - April 1, 2009 – SPP added Lincoln Electric Systems, Nebraska Public Power District, and Omaha Public Power District.
  - October 1, 2015 – SPP added the Integrated System (WAPA-Upper Great Plains, Basin Electric Power Cooperatives, Heartland Consumers Power District, and Northwestern Energy).
- SPP is the sole-balancing authority for the region. The region is comprised of five resource zones.
- Transmission flows are generally characterized by southward and eastward flows, particularly from high-wind power resources to load centers. Five of the largest load centers are among the top 100 cities in the United States: Kansas City, Oklahoma City, Tulsa, Omaha, and Wichita.
- According to SPP's market monitor, most of the highest congested corridors on the SPP system are significantly impacted by inexpensive wind generation. Of the 10 most congested flow gates, those affected the most by wind generation are the west-to-east flows through the Hays, Kansas area, and west-to-east flows in eastern Oklahoma. The southwest Missouri area is also impacted by wind and external flows. Projects are planned throughout the SPP footprint which provide for more transfer of wind generation from west to east.

Sources: SPP 101; OMS-RSC Seams White Paper; SPP SOM 2018

Transmission Topography and Investment (Cont'd)

SPP-WECC and SPP-ERCOT DC Ties



SPP-WECC ties SPP-ERCOT ties

Source: SPP 101

- The region is characterized by transmission seams to the west (with the Western Interconnection and the Western Electric Coordinating Council in particular), to the south (with the Electric Reliability Council of Texas), and to the east (with MISO).
- There are seven HVDC ties between SPP and the Western Interconnection with transfer capacity ranging from 100 MWs to 200 MWs.
- On its eastern boundary with MISO, SPP has 171 total tie lines in voltages ranging from 69 kV to 500 kV.

SPP-Western Interconnection DC Ties

HVDC Station	Location	kV	Power (MW)
David A. Hamel	Stegall, NE	50	100
Eddy County	Artesia, NM	82	200
Blackwater	Clovis, NM	60	200
Miles City	Miles City, MT	82	200
Virginia Smith	Sidney, NE	50	200
Rapid City	Rapid City, SD	13	200
Lamar	Lamar, CO	63.6	210

Source: SPP Seams Study Update

SPP-MISO AC Ties

Voltage Level (kV)	# of Tie-Lines
69	78
115	28
138	4
161	24
230	20
345	14
500	3
Total	171

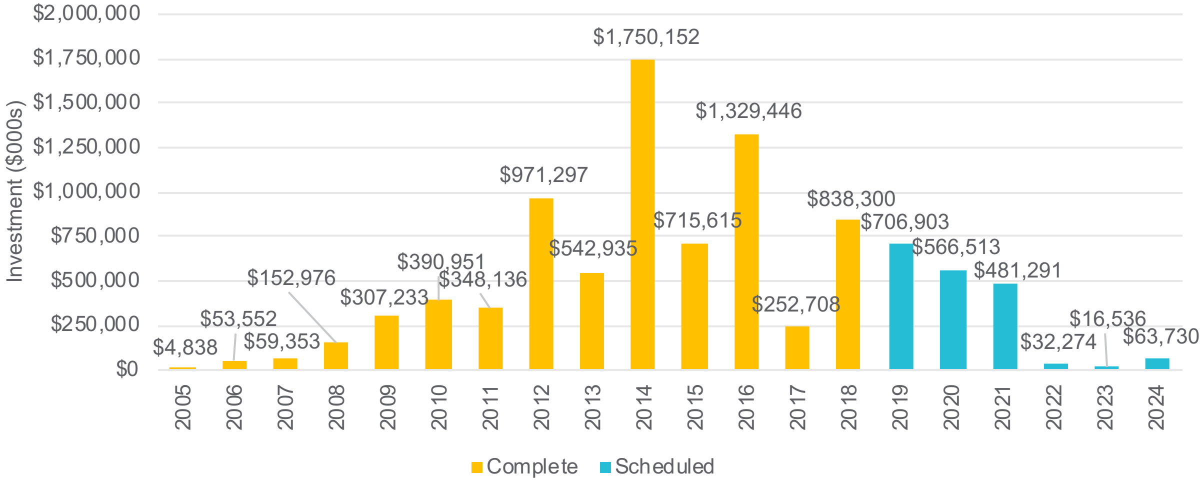
Source: OMS-RSC Seams White Paper

Sources: SPP 101; OMS-RSC Seams White Paper; Seams Study Update

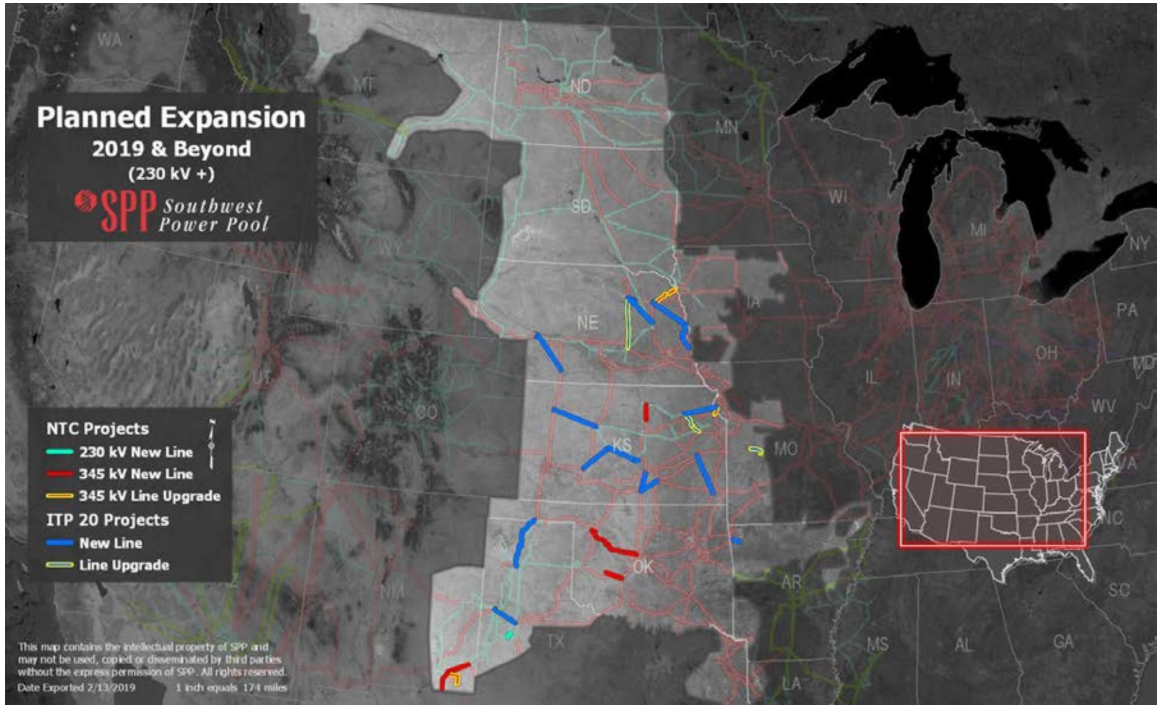
Transmission Topography and Investment (Cont’d)

- Transmission congestion in central Kansas, eastern Oklahoma, and southwest Missouri is the focus of near-term upgrades and new high-voltage lines per SPP’s transmission plan (see right). Note, however, that ITP’s 20 projects are planned upgrades and not commitments.
- Since 2005, SPP has directed $7.7 billion in completed projects and $1.9 billion in scheduled projects (see below).
- SPP planning weighs the cost of transmission investment against the cost savings in the form of reduced outages, congestion, losses, and lower production cost. SPP recently analyzed $3.4 billion in investment during 2012-14 (including extra high-voltage projects) and estimated a benefit-to-cost ratio of 3.5x over a 40-year period, with production cost savings benefits of $16.6 billion. This did not factor in public policy or reliability benefits.

Transmission Investment Directed by SPP (2005–2024)



SPP’s Transmission Expansion Plan (as of Feb. 2019)



Source: SPP State of the Market 2018

Sources: SPP 101; OMS-RSC Seams White Paper; SPP SOM 2018; SPP Value of Transmission
Notes: NTC means notification to construct (i.e., received a written notice from SPP to construct a transmission project that was approved by the SPP board of directors). ITP 20 means long-term integrated transmission plan recommended upgrades.

Resilience Issues

- The area covered by SPP is a broad area with a diverse array of industries and weather. As a frame of reference for the potential economic impact of a resilience event, SPP's 2018 annual GDP for those states in its footprint (excluding Texas) was $2 trillion.*
- In SPP's comments to FERC in its grid resilience docket, it cites the following resilience risks in its region:
  - Weather events are the primary naturally occurring risks to resilience, including severe events such as tornadoes, which can destroy significant portions of the bulk power system.
  - SPP has also experienced drought conditions, which could result in impacts to hydroelectric generation and supplies of cooling water for thermal generation.
  - The region can also experience ice storms that can result in significant system outages.
  - SPP also identified other potential naturally-occurring issues including: (1) upper-atmosphere instability resulting in sudden ramping of wind generation; (2) unseasonably high temperatures resulting in high-loading during generators' scheduled maintenance periods; (3) flooding of substations and power plants near waterways; (4) electromagnetic pulse or geomagnetic disturbance events that damage control systems and/or protection systems of multiple substations; (5) grass fires; and (6) severe earthquakes damaging infrastructure.
- A key human threat is vandalism, which SPP characterizes as usually localized in terms of impact, but could conceivably be attempted on a larger scale. Vandalism or sabotage events can include cyber-attacks impacting critical systems or infrastructure, sabotage of substations or transmission lines, and damage to communication infrastructure. Other potential human-caused issues include fires in control centers and software errors or limitations causing malfunction of critical systems.
- SPP also considers capacity availability an important characteristic of resilience and points to its fuel-indifferent approach to transmission system planning that it has developed to ensure resourcefulness. SPP pointed to the approval and development of more than $10 billion in transmission infrastructure that has enabled resources of all fuel types to help meet customer demand during a range of potential threats to reliability and resilience.
- As planning coordinator, SPP has coordinated with transmission planners in the footprint to identify potential for lower frequency (N-2) extreme events. In addition to identifying potential impacts, SPP also reviews annually the state of equipment with long lead times (i.e., that would take more than a year to replace).

*Note: Figure applies to states of AR, IA, KS, LA, MN, MO, MT, NE, NM, ND, OK, SD, WY
Sources: SPP Resilience Testimony; Bureau of Economic Analysis

Resilience Issues (Cont'd)

Recent Resilience Issue: The South Central United States Cold Weather Bulk Electric System Event of January 17, 2018

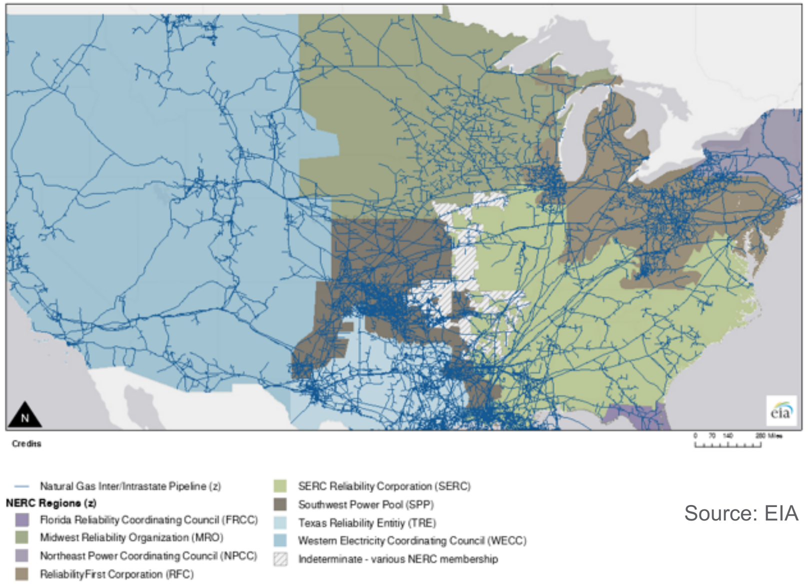
- **Summary:** On January 17, 2018, a large area of the south central region of the United States experienced unusually cold weather. Below average temperatures began to occur as early as Friday, January 12, from the Great Plains south through the Mississippi Valley. Going into the work week beginning Monday, January 15, MISO, SPP, and other adjacent areas knew that Wednesday, January 17, was likely going to be the coldest day of an extremely cold week for much of their respective footprints. The below average temperatures in this area resulted in 183 individual-generating units within the footprints of SPP, MISO, TVA, and SERC experiencing either an outage, a de-rate, or a failure to start between January 15 and January 19.
- **Outages and De-rates:** Between Monday, January 15, and the morning peak hour (between 7 a.m. and 8 a.m. CST) on Wednesday, January 17, approximately 14,000 MWs of generation experienced an outage, de-rate, or failure to start. Inadequate winterization was deemed a key factor.
    - Including generation already on planned or unplanned outages or de-rated before January 15, the four regions had more than 30,000 MWs of generation unavailable in the south central portions of their footprints by the January 17 morning peak hour.
    - Generator owners attributed at least 35% of the generation outages and de-rates on January 17 to the extreme weather conditions: 19% to freezing-related mechanical issues and 16% to cold-related fuel supply issues.
    - From January 15 to 19, natural gas-fired units were 70% of the unplanned generation outages and de-rates when calculated by numbers of units and 74% when calculated by MW.
    - During the same period, gas supply issues caused by the extreme cold temperatures, including interruptible supply, low gas pressure, and other pipeline and gas supply issues, led to outages of 38 units, for a total of approximately 2,200 MWs.
- **Peak Winter Demand:** At the same time (January 17 morning), power demand in MISO south and SPP was above their respective winter "extreme" forecast peak, while adjacent TVA and Southern Company footprints were above their expected "50/50" winter peak.
- **MISO Energy Emergency**: Under normal conditions, the MISO region is not capacity limited. However, with generator outages, MISO declared an energy emergency, because it had insufficient reserves to balance generation and load in the MISO South portion of its footprint, while all four MISO regions experienced system constraints. MISO was limited in its ability to move power southward within its region to 3,000 MWs, but it exceeded that limit (reaching a maximum of 4,331 MWs) subject to any potential reliability effects on adjacent regions. SPP experienced parallel flows that challenged operators.
- **Deliverability:** There was ample wind generation available in the northern portions of MISO and SPP. Deliverability of reserves was the principal issue.

Source: Jan. 2018 Event Report

Resilience Issues (Cont'd)

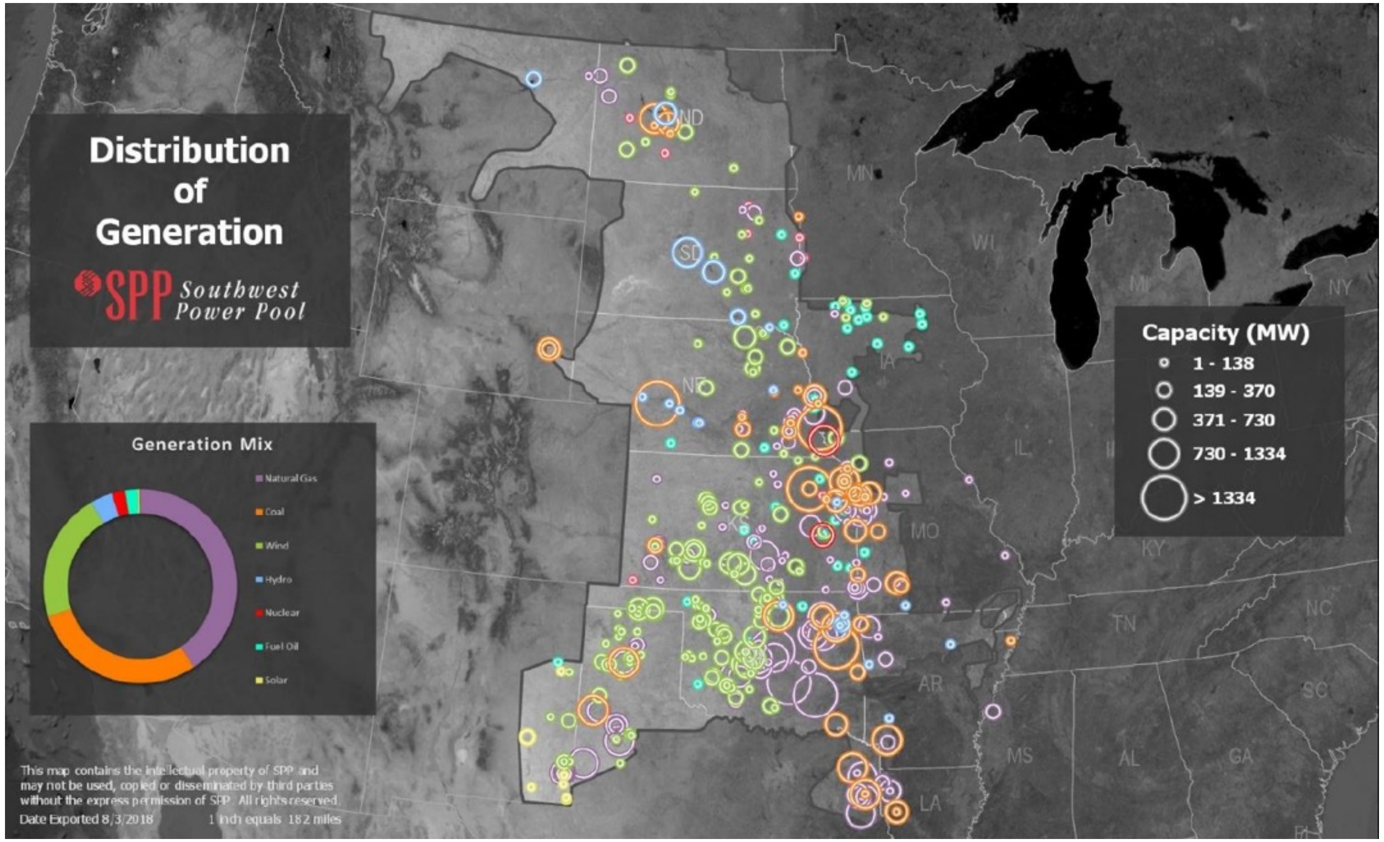
- SPP's resources are varied, but the region is mostly dependent upon wind, coal, and natural gas-fired generation. Coal and gas-fired generation are particularly concentrated in the southern and eastern part of its footprint.
- There is abundant gas pipeline availability and access in the southern portion of the region, particularly in Oklahoma, Texas, and Louisiana (see below).

Natural Gas Pipelines by Selected NERC Region



Source: EIA

SPP's Generation Capacity by Location, Size, and Fuel Type

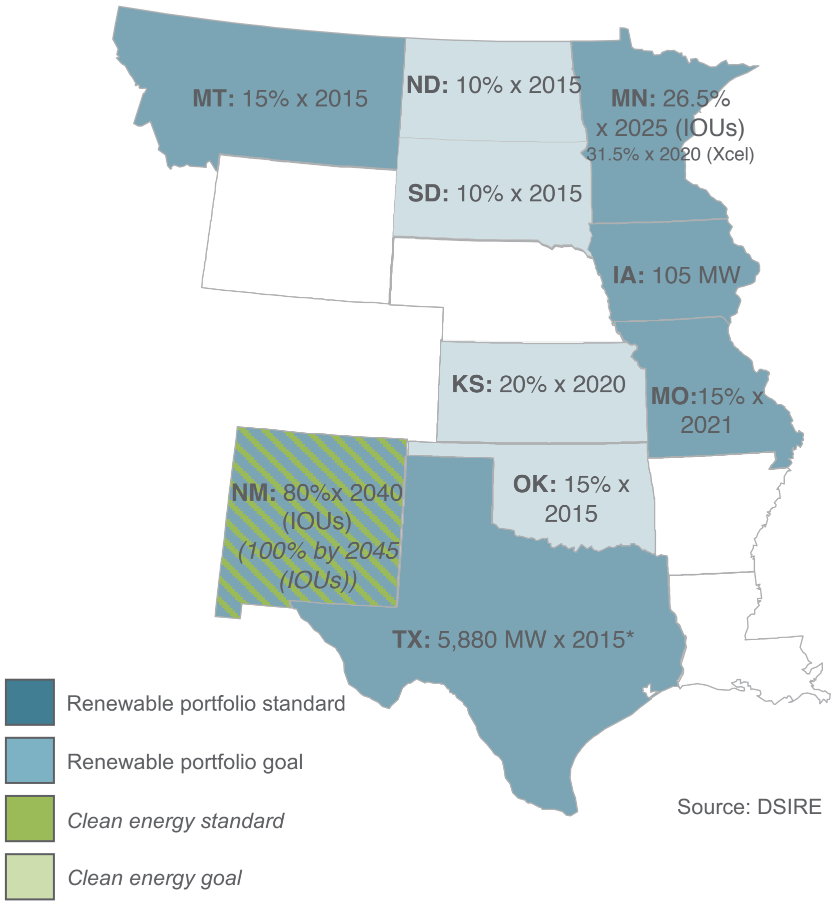


Source: SPP 101

Sources: SPP 101; EIA

Renewables Integration

State Renewable Portfolio and Clean Energy Standards and Goals within the SPP Footprint (as of June 2019)



Source: DSIRE

* Extra credit for solar or customer-sited renewables

Demand-Side Considerations

- Overall power consumption generally in the region was 248.4 TWh in 2016, fell to 246 TWh in 2017 after a cool August, but rose in 2018 by 6% to 259.6 TWh. Long-term, NERC's latest assessment forecasts a 0.5% compound annual growth rate in net energy for load over the next 10 years.
- A number of states both within and adjacent to SPP's footprint have renewable and/or clean energy standards (see left). New Mexico has instituted aggressive long-term clean energy goals (100% by 2045). Minnesota has another relatively ambitious renewables standard, requiring investor-owned utilities to procure 26.5% of their power renewables by 2025.
- Some utilities in states touched by SPP's footprint have also introduced clean energy commitments (see below).

Utility Name (States of Operation)	Goal Type	Target Dates	Description (Date Implemented)
Kansas City Power and Light (KS, MO)	Emission Reduction	2020 2021	Plan to exceed states' (KS and MO) RPS; 15% emissions reduction by 2021 in Missouri and 20% emissions reduction by 2020 in Kansas (2018)
MidAmerican Energy (IA, IL, SD)	Renewables	N/A	100% renewables (2016)
Otter Tail Corporation (MN, ND)	Renewable Energy	2031	30% renewables by 2031 (2017)
Public Service Company of New Mexico (NM)	Emission Reduction	2040	100% emissions-free energy by 2040
Xcel Energy (CO, MI, MN, NM, ND, SD, TX, WI)	Emission Reduction/ Carbon Reduction	2017 2030 2050	35% emissions reduction by 2017 (achieved), 80% below 2005 levels by 2030, and zero-carbon by 2050 (2015)

Source: SEPA

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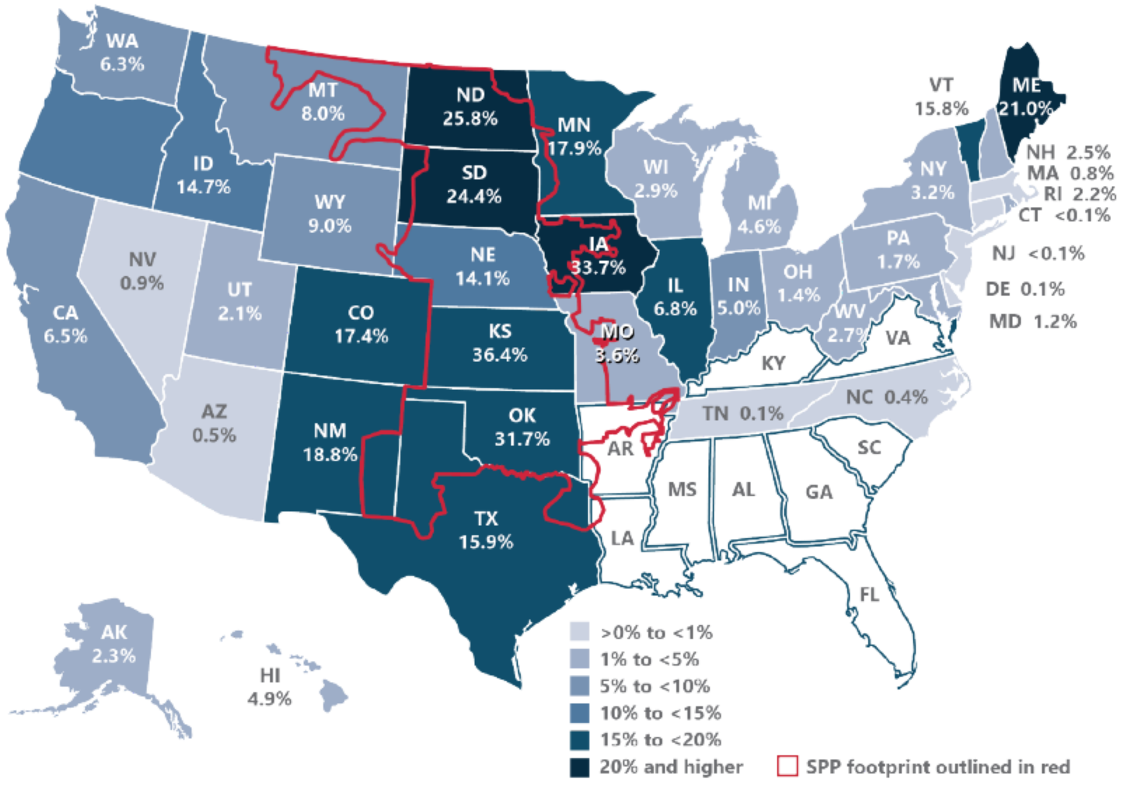
Sources: SPP 101; SEPA; DSIRE; NERC ES&D

Renewables Integration (Cont'd)

Supply-Side Considerations – Wind Resources

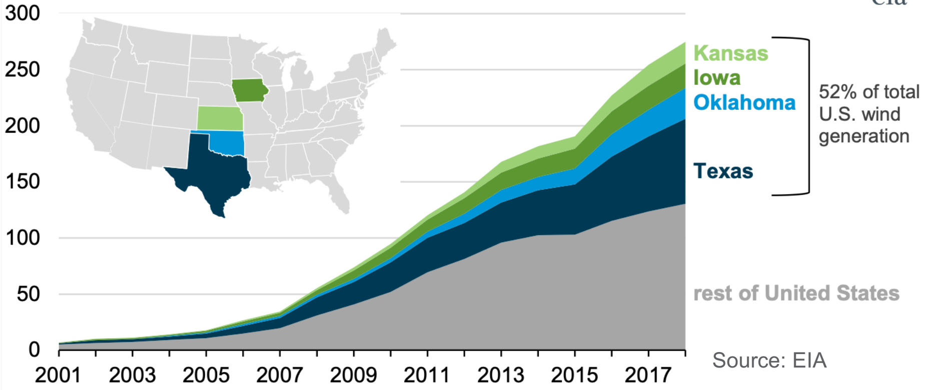
- SPP has significant wind resources, both installed and potential. Outside of offshore areas, SPP's footprint, highlighted on the map, is covered with some of the highest wind speeds in the country.
- According to EIA, U.S. wind generation totaled 275 million MWhs in 2018, with more than half coming from four states: Texas, Oklahoma, Iowa, and Kansas.
  - Texas accounted for more than 25% of U.S. wind electricity generation in each of the past three years. Most wind-generating capacity in Texas is located in the rural northern and western areas of the state.
  - Oklahoma accounted for 10% of wind generation in 2018, and its wind capacity doubled between 2014 and 2018.
  - Iowa's wind production has doubled since 2011 and accounted for 34% of electricity generation in the state, second only to natural gas (44%).
  - Kansas became the fourth-largest wind power producer in 2016, and wind accounted for 36% of electricity generation in 2018, the largest proportion of any state.

Wind Energy's Share of Electricity Generation by State (2018)



Source: SPP (citing EIA)

Wind electricity generation in the United States (2001-2018)
million megawatthours



Source: EIA

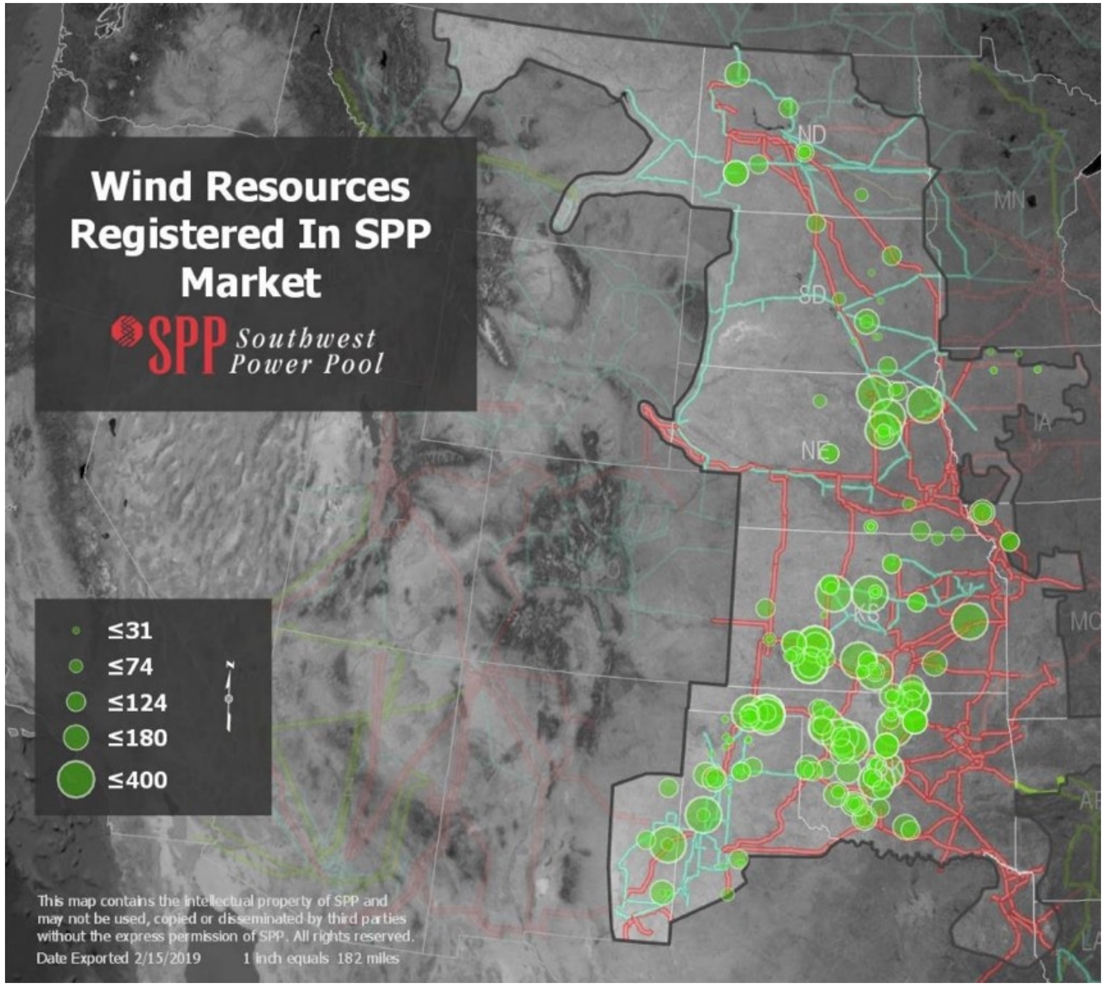
Sources: SPP 101; EIA; SPP SOM 2018

Renewables Integration (Cont'd)

Supply-Side Considerations – Wind Resources (Cont'd)

- SPP has about 21 GWs of wind installed today, comprised of 11,029 turbines at 207 wind resource locations (most are 80-meter hub height).
  - Across SPP, the average 2018 wind penetration was 25%.
  - But minimum and maximum output can see wide swings: the maximum one-day wind swing was more than 13 GWs (in 18 hours) and the maximum 1-hour ramp was 3.7 GWs.
  - Typically, wind generation fluctuates seasonally as summer is the low-wind season, while spring and fall are high-wind seasons. Wind also typically has lower production during on-peak hours than off-peak. Higher levels of wind generation tend to coincide with the morning ramp periods.
- In the pipeline, the region has about 9 GWs of unbuilt wind facilities with signed interconnection agreements and a total of about 50 GWs of wind generation in all stages of study and development as of June 2019.
- SPP forecasts about 23 GWs of wind installations by 2020 (more than its current minimum load) and 28 to 33 GWs forecast total installed wind generation in 2025.

Installed and Registered Wind Resources in SPP's Market

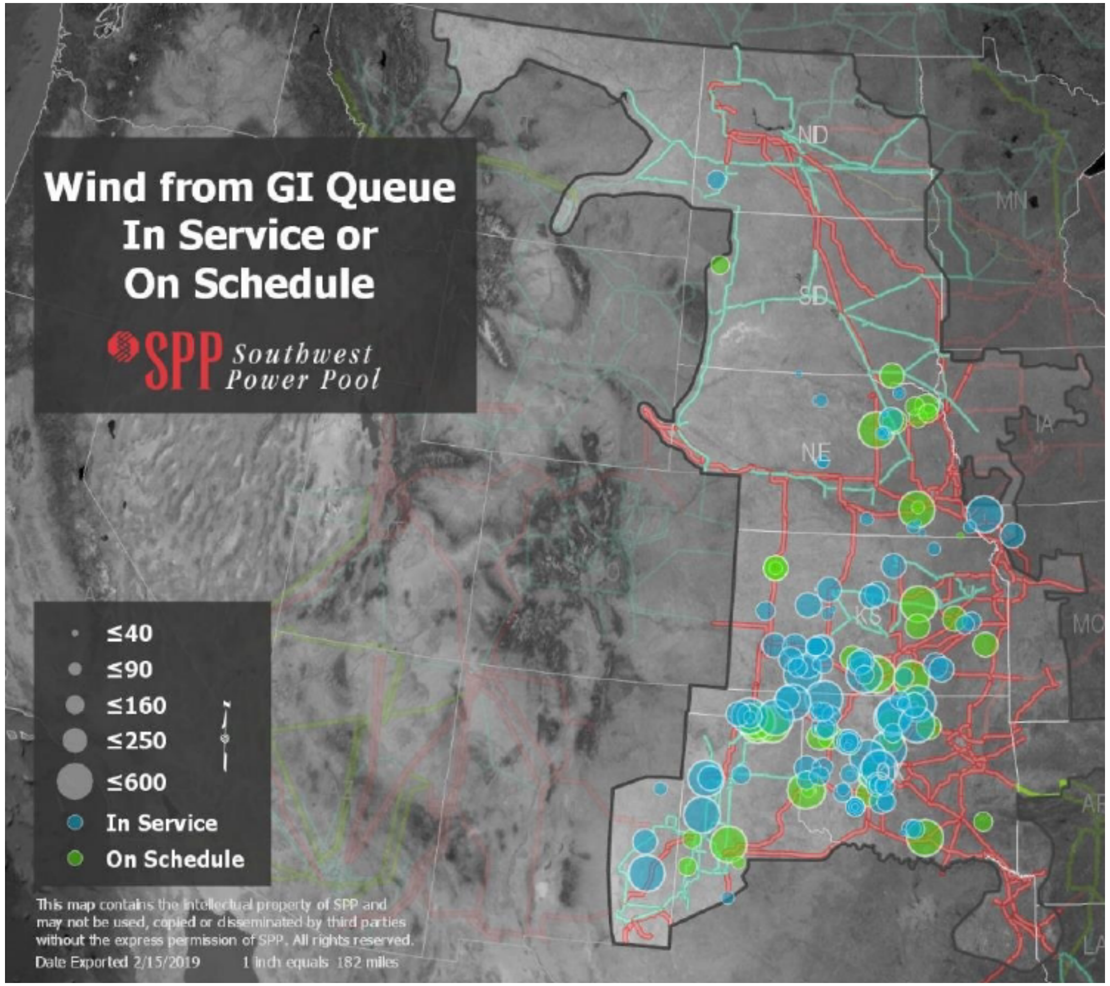


Source: SPP 101

Sources: SPP 101, at pp. 39, 123; SPP SOM 2018

Renewables Integration (Cont'd)

Wind Resources in SPP's Generation Interconnection Queue In-Service or On Schedule (as of Feb. 2019)

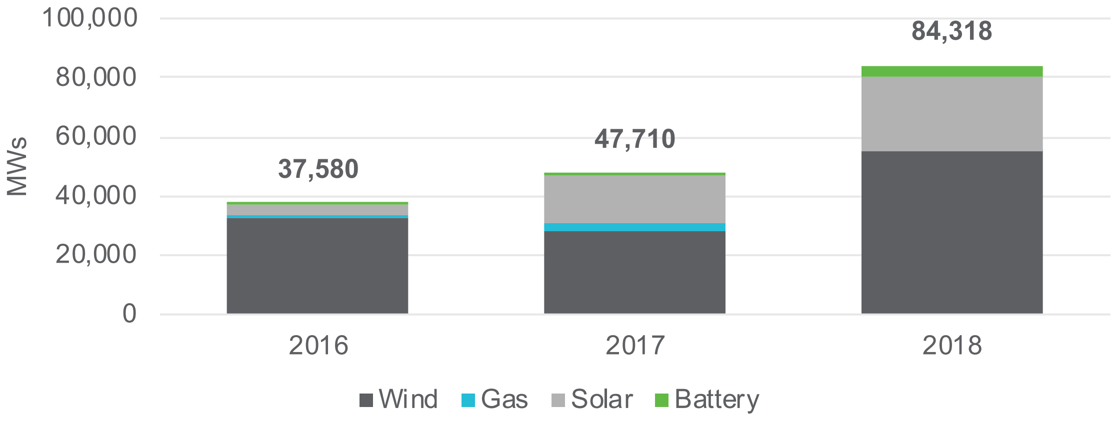


Source: SPP 101

Supply-Side Considerations – Wind Resources (Cont'd)

- Wind resources continue to seek interconnection largely in the southern half of SPP (see next page).
- Increasingly, however, solar power resources are being considered in the footprint as well. Currently, there are 215 MWs of solar capacity in SPP, largely concentrated near the Texas-New Mexico border, where solar irradiance is more supportive of solar photovoltaic power generation. More than 24 GWs of solar capacity had generation interconnection requests in the queue at the end of 2018.
- Battery interconnection requests have increased as well, growing along with solar interconnection requests (see below).

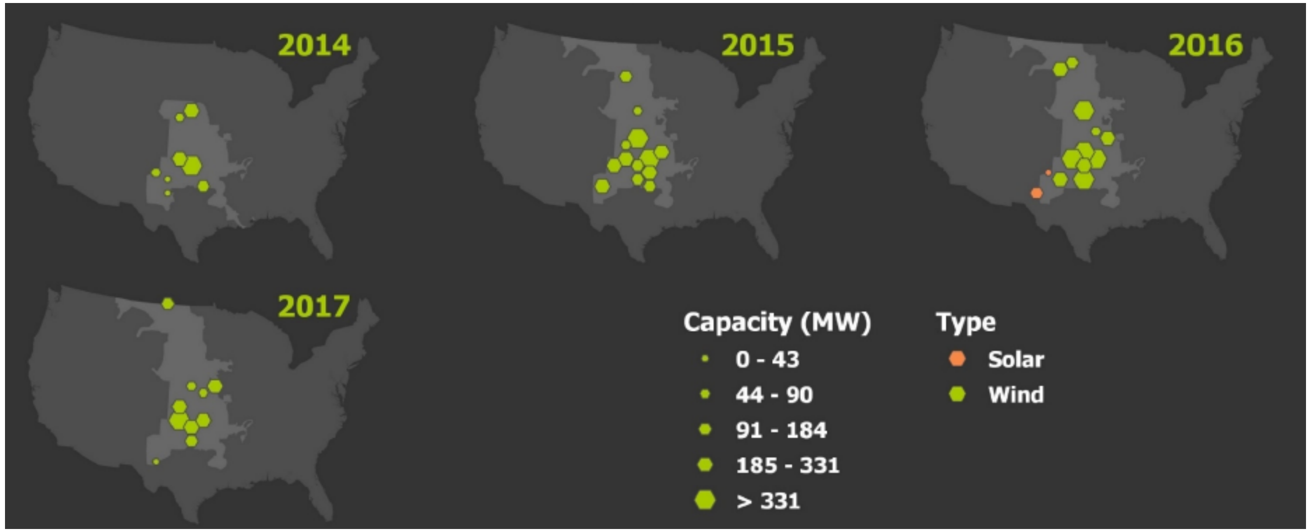
Active Generation Interconnection Requests (MWs) (as of Year-End 2016–2018)



Source: SPP 2018 State of the Market, Fig. 2-15

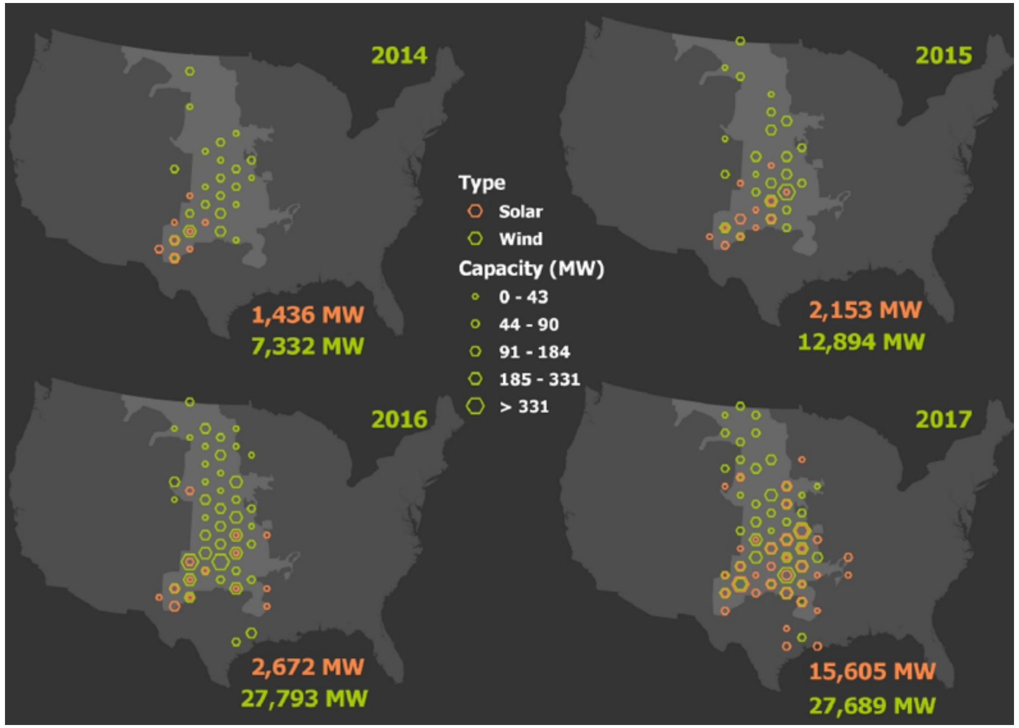
Renewables Integration (Cont'd)

Comparative Distribution of New Renewable Resources (2014–17)



Source: SPP 101

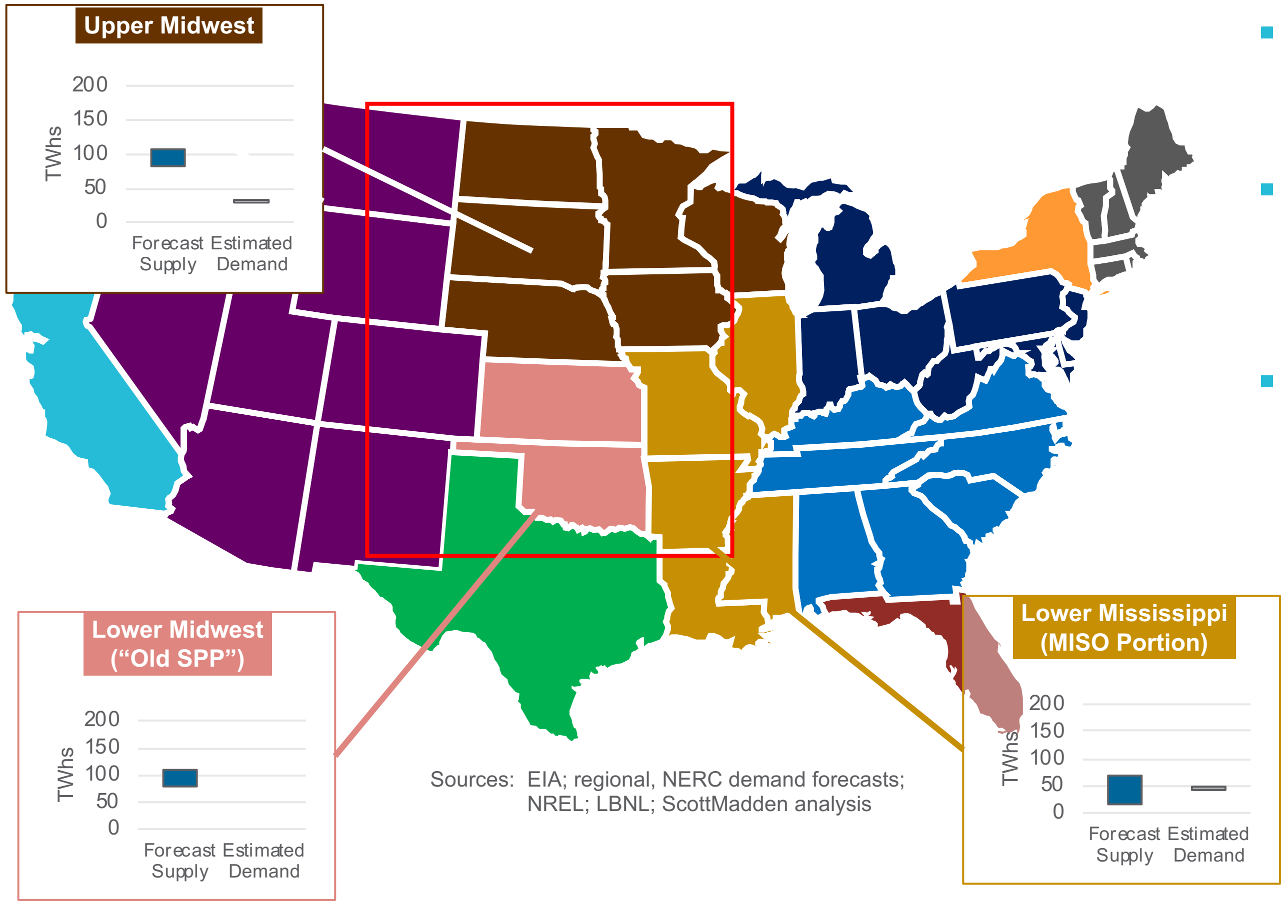
Comparative Distribution of Renewable Interconnection Requests (2014–17)



Source: SPP 101

Source: SPP 101

Renewables Integration (Cont’d)

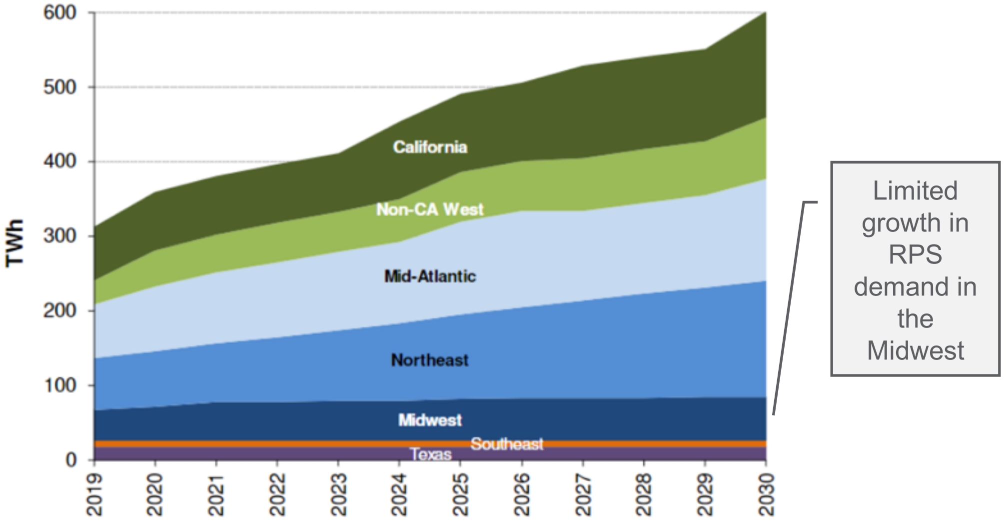


Sources: EIA; regional, NERC demand forecasts; NREL; LBNL; ScottMadden analysis

Integration Challenges – RPS Supply and Demand

- As seen in the map at left and the Midwest section of the chart below, the SPP region has abundant anticipated renewable resource supply in comparison with projected renewables demand, which is supposed to grow only modestly through 2030 under current state policies.
- Lawrence Berkeley National Laboratory (LBNL) notes that RPS capacity additions (10% or 9 GWs) extend to 13 states without an RPS, with the most significant including MISO states Indiana and North Dakota as well as Wyoming. Two others with no further RPS obligations—Kansas and Iowa (each part of SPP)—host significant RPS capacity for others.
- This RPS supply-demand imbalance illustrates the role of interstate transmission capacity for interstate commerce for RPS compliance.

Projected U.S. RPS Demand (Total Compliance Requirements) per DOE LBNL (2019–2030) (as of July 2019) (in TWh)



Source: LBNL

Sources: LBNL 2019 RPS Analysis; AWEA 2019 RPS Analysis; EIA; regional, NERC demand forecasts; NREL Standard Scenarios; LBNL; ScottMadden analysis

Renewables Integration (Cont'd)

Integration Challenges (Cont'd)

- Wind integration brings low-cost generation to the SPP region but does not count for much accredited capacity.
- According to SPP's market monitor, there are a number of operational challenges in dealing with substantial wind capacity:
  - Wind energy output varies by season and time of day. This variability is estimated to be about three times more than load when measured on an hour-to-hour basis.
  - Wind is counter-cyclical to load. As load increases (both seasonally and daily), wind production typically declines. The increasing magnitude of wind capacity additions since 2007, along with the concentration, volatility, and timeliness of wind, can create challenges for grid operators with regard to managing transmission congestion and resolution of ramping constraints (which began being reflected in scarcity pricing in May 2017) as well as challenges for short- and long-run reliability.
  - Wind forecast errors are also the leading cause of day-ahead and real-time price divergence, and forecast errors have led to several price spikes.
- Some "legacy" wind and other qualifying resources were allowed to register as non-dispatchable variable energy resources, provided the resource had an interconnection agreement by May 21, 2011, and commercially operated by mid-October 2012.
  - About 29% (nearly 6 GWs) of existing wind resources in SPP are non-dispatchable variable energy resources (NDVERs). These resources generally produce without regard to price, but operators must issue manual instructions to reduce or limit output at certain times.
  - Penetration of these NDVERs has led to occasional reduction in dispatchable wind resources, largely to alleviate congestion bottlenecks.
  - An increase in dispatchable wind capacity has helped in the management of congestion caused by high levels of wind generation in some of the western parts of the SPP footprint.
- Substantial transmission upgrades in SPP's footprint over the past few years have provided an increase in transmission capability for wind-producing regions, helping to address concerns related to high-wind production and resulting congestion. The increased transmission capability directly reduces localized congestion, creating a more integrated system with higher diversity and greater flexibility in managing high levels of wind production. However, given the historical trends toward growing wind capacity and indicators of future additions in the generation interconnection queue, additional transmission upgrades may entice further development of wind capacity.

Source: SPP SOM 2018

Renewables Integration (Cont'd)

Integration Challenges – Integrated Marketplace

- SPP operates an Integrated Marketplace, with greater than 6 GWs of AC interties with MISO to the east, 810 MWs of DC ties to ERCOT to the south, and more than 1 GW of DC ties to WECC to the west. Additionally, SPP has more than 1,500 MWs of interties with the Southwestern Power Administration (SPA) in Arkansas, Missouri, and Oklahoma, and more than 5 GWs of AC interties the Associated Electric Cooperative (AECI) in Oklahoma and Missouri.
- SPP has been a net exporter in real-time since 2016. Notably, because of the addition of the Integrated System to SPP in October 2015, transactions that were external imports from WAPA became internal transactions within the SPP footprint. SPP's exports closely follow wind production for the day.
- The Integrated Marketplace has reliably managed wind generation even when it represented more than 60% of load. While use of manual dispatch is limited and SPP's dispatchable wind fleet is growing, SPP needs ramping capability. Ramp shortages have been reflected in prices since May 2017.
- One issue SPP is addressing is "price chasing," where a NDVER on manual control responds to lower real-time prices by curtailing output and increasing output when prices rise. The latter can cause breaches on flow gates, causing suboptimal dispatch and reduced market efficiency.
- SPP has proposed expanding its current market offering to include a Western Energy Imbalance Service (WEIS), extending into the Western Interconnection. This five-minute energy imbalance market will use non-firm, "as-available" transmission service with lowest priority offered at zero cost. By incorporating a wide variety of dispatchable resources (including dispatchable variable energy resources), the objectives of WEIS are to optimize the use of the Western Interconnection's transmission system and minimize overall costs of energy and capacity.

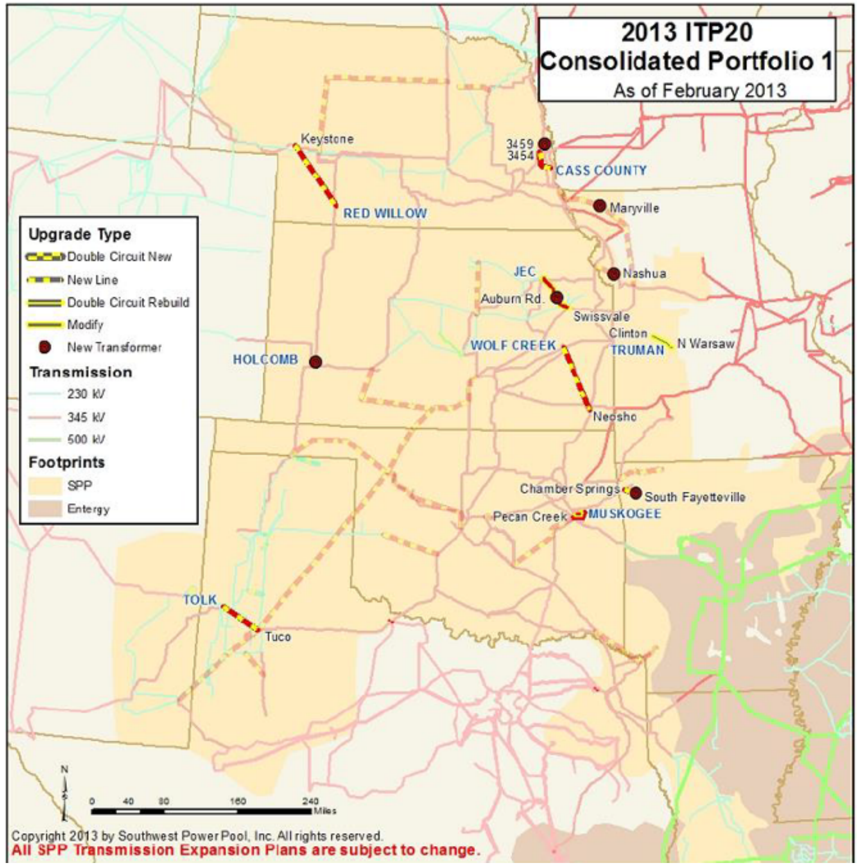
Sources: SPP SOM 2018; WEIS Proposal

Renewables Integration (Cont'd)

Renewables Integration – ITP20

- SPP performs a long-range (20-year) planning exercise every five years (termed ITP20). Its latest ITP20, issued in mid-2013, looked at five scenarios, each driven by policy considerations, such as state renewable mandates, a potential federal renewable standard, EPA regulations, and additional wind development for export.
- SPP's recommended portfolio of transmission projects assumed 9 GWs of wind capacity additions (NB: less than currently projected) allocated through the region in six states. This assumed meeting then-existing state renewable mandates. It also assumed that 15.2 GWs of gas-fired resources (7.5 GWs combined cycle and 7.7 GWs combustion turbine) would be added to the system.
- Under its base case plan, SPP's model found that there was additional congestion, leading to curtailment of scheduled wind energy output. Levels of curtailment varied by scenario, with greater wind capacity leading to more curtailment.
- Using N-1 planning, ITP20 identified eight reliability, three economic, and one seams projects, respectively, totaling $560 million in engineering and construction costs.
  - In evaluating extra-high voltage (EHV) transmission, solutions recommended were primarily 345 kV technology.
  - However, in higher wind penetration scenarios (e.g., 16.5 GWs for internal transfers plus 10 GWs for exports), 765 kV and HVDC solutions were considered. In higher wind penetration scenarios (15 to 25 GWs compared with 9 GWs), incremental transmission investment of $1.3 billion to $5.1 billion would be required.
- Note that this plan predates the expansion of SPP to the north.

2013 ITP20 Transmission Plan



Source: ITP20, Fig. 0.1

Source: ITP20

Renewables Integration (Cont'd)

Integration Issues – 2016 Wind Integration Study

- In 2014, SPP launched its Integrated Marketplace. In 2015, the Integrated System* was added as a SPP member. With a broader footprint and market structure in place across its footprint, SPP conducted a wind integration to determine operational and reliability impacts of additional wind generation in SPP, including in the Integrated System's region in the north.
- In 2016, SPP conducted a wind integration study in which scenarios with 30%, 45%, and 60% wind generation were analyzed. It found that up to 60% of wind penetration could be accommodated, but additional investments and capabilities would be required.
- Key findings from the study:
  - Thermal and voltage analysis indicated that approved ITP projects needed to be expedited, and the study identified additional transmission needs.
  - Voltage stability analysis showed that renewable penetration levels were (at the time of the study) approaching their limits, requiring dynamic reactive reserves.
  - Wind has a small impact and large ramps showed a small increase, but time periods during which large-ramping occurs are less predictable. New ancillary services products to address intra-hour ramping or situational awareness tools (e.g., phasor management unit applications) to address inter-hour ramping may be needed.
  - All N-1 constraints were able to be resolved with redispatch, albeit with heavy-wind curtailments in higher penetration cases, leaving thousands of MWs of low-variable cost generation "on the table" due to significant transmission constraints.
  - Even without transmission outages, significant overloads were observed on multiple facilities.

Integration Issues – 2017 Variable Generation Integration Study

- In a subsequent technical integration study of SPP variable generation (wind and solar), SPP looked at N-2 fault locations, primarily focused on system frequency behavior with loss of selected large-generating units as well as five-minute analysis for ramping. The study found the following:
  - The SPP system could withstand high levels of wind resources, but scenarios were identified when the loss of certain output of one generator (Wolf Creek, KS, 1,255 MWs) could jeopardize system security.
  - While no ramping issues were identified, those scenarios assumed correct forecasts. The study recommended further analysis to quantify the risk and expectation for forecast errors. Ramping deviation can have significant impacts, especially during winter mornings, when 2 to 3 GWs of generation might require start-up at a time of negative system prices.

Note: *The Integrated System covers a seven state area (IA, NE, SD, WY, MN, ND, and MT) and consists of more than 9,300 miles of transmission lines. It is jointly owned by Heartland Consumers Power District, Western Area Power Administration's Upper Great Plains Region, and Basin Electric Power Cooperative.
ITP means integrated transmission plan.

Sources: 2016 Wind Study; 2017 Variable Gen. Study

Implications for Transmission

	Resilience	Integration of Renewables	Other Factors	Transmission Opportunities
Southwest Power Pool	▪ Key risks largely weather-related: severe events (tornadoes), drought, ice storms ▪ Monitor N-2 extreme events; annual review of long lead-time equipment ▪ Geographic diversity (broad north-south footprint) affords weather diversity as well as multi-threat exposure	▪ About 21.5 GWs of wind, with penetration of 25% average generation as % of load; only a small amount of solar ▪ Renewable (wind) penetration record of 71% in April 2019 ▪ Operational challenges as nearly a third of wind capacity is non-dispatchable ▪ Significant renewables and storage (99%) in planning queue: 51 GWs wind, 28.5 GWs solar, and 5.8 GWs storage ▪ Forecast 28–33 GWs installed wind by 2025 ▪ Some ramp shortages occurring; daily variation in resources requires optimization over broader area, diverse fuels (e.g., max wind swing of 13.3 GWs over 24 hours) ▪ Congestion is declining across footprint, but regional effects remain: northwest/southeast split of region, with wind causing congestion in central KS and southwest MO	▪ Scenario planning (20 years) through SPP's 2013 ITP20 examines various levels of wind penetration, from 10 GWs to 26.5 GWs – Scenarios included federal renewable energy standards, exports – Did not account for significant solar now seen in queue ▪ Relatively homogeneous state policy environment across footprint; modest clean energy goals except for NM, MN ▪ 2016 analysis showed that $3.4B in transmission expansion projects in 2012–14 including 1,800 miles of extra high-voltage backbone projects expected to yield benefits of $16.6B over 40 years, including $10.5B of production cost reductions and $1.3 billion in optimal wind development	▪ About $10B in transmission infrastructure investment made to improve resource deliverability ▪ Potential increased integration with western balancing authorities, TX ▪ Resilience benefits from transmission for renewable integration ▪ About $1.9B in scheduled transmission investment (2019–2024) ▪ Last 20-year plan identified $845M for 12 projects (8 reliability, 3 economic, 1 seams) at 345 kV assuming only 9 GWs of wind capacity ▪ Investigating seams coordination with MISO to east; latest (2016) coordinated system plan identified 7 targeted needs and identified one interregional project ▪ 2018 plan calls for 13 projects totaling $37M, largely in SD, KS, MO, AR, TX; $32M for lower voltages (115, 69 kV) ▪ Continued development of west-to-east transfer capability to relieve "pinch points"

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